Exhibit A
NEC Analysis of Power Lines as Radiators

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June 22, 2004

1. Method of Moments Modeling

1.1 Method-of-moment antenna-modeling techniques have been used extensively by various entities and individuals providing comments in ET Docket 04-37, "Amendment of Part 15 Regarding New Requirements and Measurement Procedures for Access Broadband Over Powerline Systems." Although ARRL supports the use of such modeled results, having used them itself in the earlier Notice of Inquiry (NOI) and in this Notice of Proposed Rulemaking (NPRM), the models used must be a reasonable representation of the way overhead power lines are configured. ARRL does not agree that the models provided in this proceeding by Ameren Energy Communications (AEC) are an accurate representation of power lines used to carry BPL signals. AEC has provided the Commission with models and calculations of perfectly balanced lines. Power lines as deployed are poorly balanced and BPL couplers do not feed the power lines as described by AEC. AEC also has not properly modeled the way that fields vary with slant-range distance from their power-line models at the angle and height of maximum emissions. Its modeling is incorrectly presuming that an extrapolation that applies to their models at 1-meter height is representative of the way fields vary with distance at other heights above ground.

2. Use of Magnetic Loop

2.1 AEC states that it does not believe that a magnetic loop antenna can be used to make measurements in the near-field region. They claim that such measurements cannot accurately be correlated to electric field strength as specified in the Part 15 regulations. Although this may be true for any arbitrarily chosen point in space, ARRL's comments showed that *if the point of maximum magnetic field strength is found* at a particular distance from the line, this has a reasonable correlation to the nearby point of maximum electric field strength. While this correlation is not perfect in the near field, it will generally be more accurate and repeatable than electric-field measurements typically made on frequencies below 30 MHz with a short vertical antenna over ground of unknown and unknowable characteristics.

2.2 ARRL notes that some loop antennas lack sufficient sensitivity to make measurements of magnetic fields at or near the FCC Part 15 limits. The FCC's test procedures should caution against this possibility and should require that the measured ambient levels be at least 6 dB higher than the input noise level of the test instrumentation used at all frequencies being measured. In general, an active loop antenna must be used and at lower frequencies, it may be necessary to use a tuned, active loop to improve sensitivity. The measured levels must also be at least 6 dB higher than the other ambient noise and signals present at the measurement point.

2.3 Although ARRL believes that the present FCC radiated emissions limits that apply to carrier-current devices are set too high for a radiator with the characteristics of power lines carrying BPL signals, it does want to see systems measured accurately irrespective of the limits the FCC may ultimately choose. For this reason, based on its extensive experience with antenna modeling that were used to help the Amateur Service comply with the FCC rules on human exposure to RF energy, ARRL supports the FCC's recommendation to use a magnetic loop antenna to attain the most reliable and accurate measurements[1].

3. Suitability of Models

3.1 From an electromagnetic-compatibility (EMC) perspective, real-world power line installations are complex. At RF, power lines are unbalanced by the presence of grounded conductors, transformer taps on individual phases, splices, junctions and conductor spacing that often varies from pole to pole. Most of these junctions run perpendicular to each other, adding to the complexity and unbalance. In its earlier filings in the NOI, ARRL provided the Commission with numerous models that represent specific characteristics of real-world power-line installations. In their reply comments, AEC criticized ARRL's models as being too simple to represent real-world installations. ARRL agrees with AEC that the models ARRL provided cannot exactly represent a real power line. That is precisely the reason that measurements are used to ensure compliance with radiated emissions limits. However, ARRL carefully chose its models to represent specific characteristics of power lines so that the general impact of those characteristics on measurement technique could be properly assessed and discussed.

3.2 Factors such as the efficiency of power lines as radiators are not significant to this proceeding because the limiting factor is not the efficiency of the power line, but the actual, measured radiated emissions. Irrespective of whether the power lines were efficient as radiating antennas, or inefficient, the end result would ostensibly be as measured by the various BPL manufacturers in their verification testing. To obtain the best efficiency and throughput, it is presumed that access BPL systems would reasonably be operated at the maximum permitted field strength of 30 uV/m at 30 meters from the source.

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[1] ARRL has documented this modeling extensively in its publication, *RF Safety and You.* This book is used extensively by amateur operators and others as a tool to demonstrate compliance with the rules on human exposure to RF. To calculate compliance distances in many of the tables in this publication, ARRL performed extensive E and H field modeling in three dimensions of a large number of antenna types. A number of these models were selected by the FCC OET staff for inclusion in its publication "*Evaluating Compliance With FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields –* Supplement B, *Additional Information for Amateur Radio Stations."*

3.3 In their comments to the NPRM, AEC has provided the FCC with a line drawing of a single model. This is shown in Figure A.1. Although this model could have some value in a theoretical treatment of wide-spaced transmission lines as radiating elements, it does not include most of the characteristics of power lines as discussed above. It is perfectly balanced, fed in a perfectly balanced fashion in its precise center and is terminated in its characteristic impedance at both ends in a perfectly balanced way. The only characteristics of this model that are somewhat correlated to real-world power-line installations are its height above ground and the fact that its conductor spacing is typical of the spacing of conductors on some overhead power lines.

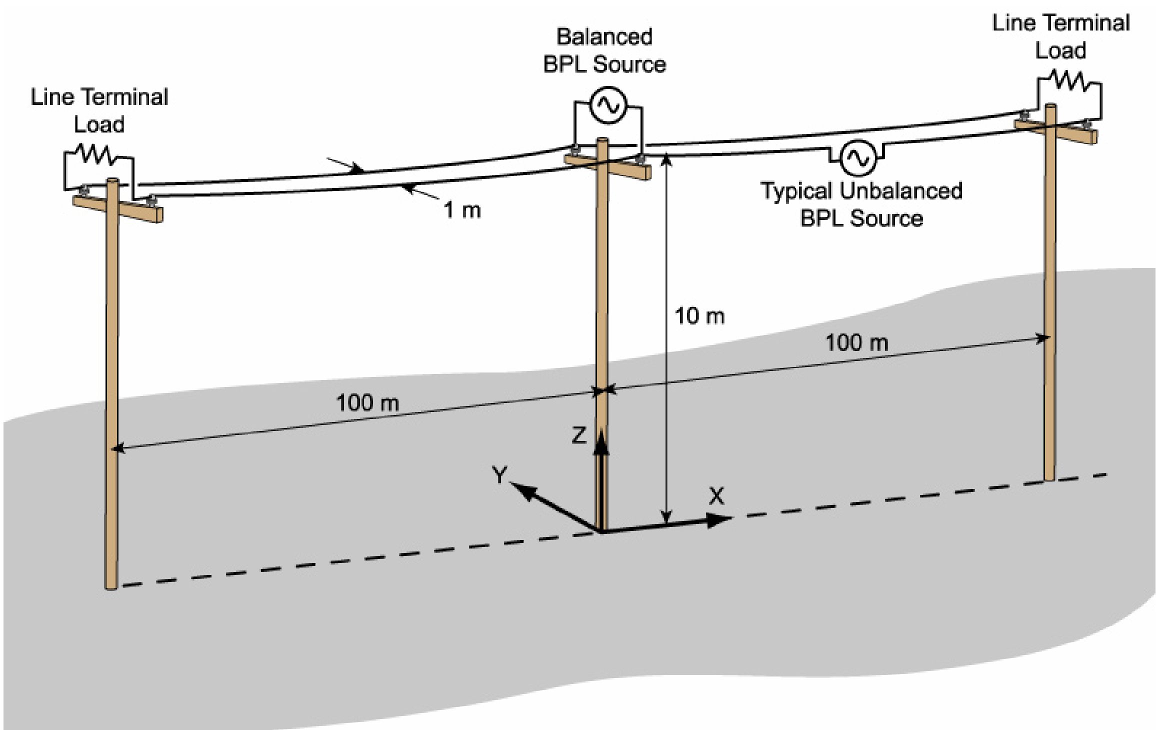

Figure A.1. ARRL used the dimensions of the model AEC described in its NPRM filing to model both the ideal balanced feed modeled by AEC and the typical unbalanced feed seen in present BPL systems.

3.4 AEC has provided the Commission with calculations showing the field-strength levels found in the reactive near-field and far-field regions of their power-line model as an antenna. The very use of these near-field terms and calculations about radiated fields would not apply to a waveguide, so ARRL presumes that AEC understands that power lines do represent a significant radiating element and ARRL agrees that such calculations are appropriate for any conductor that acts like an antenna. In actuality, power lines do function both as antennas and as transmission lines and radiate fairly uniformly along their length[2].

3.5 This is seen in a number of the models ARRL and AEC have provided to the Commission. In the figures shown in AEC's Table 1, in two cases, the field strength at points at considerable distance along the line from the ideal feed point in the center of the antenna are at the same level or higher than they are in the center. (This does not demonstrate a point source.) In considering all the graphs, the field strength level at points along the power line that are not close to the source ranges from approximately –8 dB to +0.25 dB from the field strength present near the source. Typically, the distant point along the line is attenuated by only about 4 dB from the value near the source, demonstrating that even this ideal power line is not a point source. This has also been shown in the antenna modeling provided by ARRL, NTIA and in measurements in BPL areas made by a number of entities.

4. Non-Ideal Models

4.1 The AEC model shows a transmission line fed perfectly differentially. This is *not* the way that real-world BPL systems feed overhead power lines. Although ARRL has not looked at every installation, the following photographs show the way that BPL coupling devices feed only a single phase in an unbalanced fashion. ARRL has noted this unbalanced feed in BPL installations in Potomac, MD; Briarcliff Manor, NY; Emmaus, PA; Whitehall TWP, PA and Hanover TWP, PA, using BPL equipment manufactured by Current Technologies, Main.net, Amperion and Ambient. In additional testing done in other cities, Metavox has seen similar unbalanced couplers feeding a single phase.

[2] An example of this is seen in what is known as "leaky coaxial cable." Leaky coax has slots cut in the side so that it will radiate along its length. Unshielded, wide-spaced "transmission lines" will do so to an even greater degree.

Figure A.2. BPL couplers do not feed power lines differentially. They generally feed one phase the same way that a center-fed wire antenna would be fed.

4.2 In its filings in the NOI, ARRL provided the Commission with calculated results from models with a feed method that simulated the way that BPL couplers are connected only to a single phase. ARRL fed that phase at a point 25% from one end. In ARRL's models filed with the NOI, the other phase was grounded at one point, to simulate the way that transformers or grounded "neutral" wires on the structure affect the way it radiated RF energy. The following Figures A.3 and A.4 show the significant difference between these models chosen to represent real-world conditions and the idealized model that AEC provided with its comments. In the models ARRL created for this Exhibit, ARRL used the dimensions from AEC's model and fed it balanced or unbalanced, as described in the subsequent portions of this paper. The unbalanced feed is connected to one phase, at a point 50 meters from the center of the 200-meter line power line.

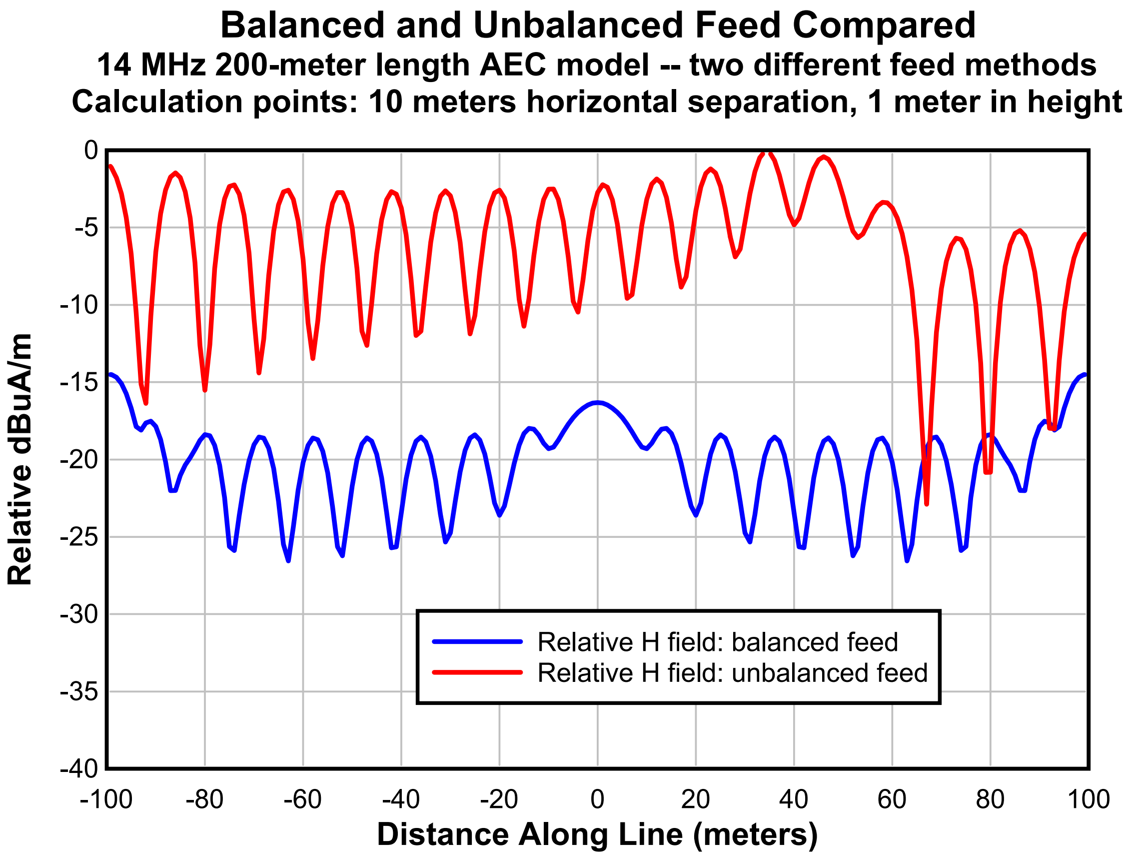

Figure A.3. This shows the significant differences between the predicted field strength from the ideal balanced feed used in the AEC model (lower line) and the fields seen when this model is fed the way that most present BPL systems are fed. The AEC model cannot be used to show the effect of the unbalanced feed that is used in all of the BPL systems ARRL has inspected. The AEC model does not correlate well with even a simple real-world model of an unbalanced feed. Even so, these models show that the method of feeding the power line does not substantially change the fact that the line radiates fairly uniformly along its entire length. If both lines radiate at 30 uV/m 30 meters from the source, interference to nearby receivers using the same spectrum will occur along the length of the line.

5. Grounding and Other Unbalance

5.1 The AEC model does not ground any of its conductors. This further deviates from real-world installations. The following graph compares the AEC idealized model with the same power line fed on a single phase in an unbalanced fashion (with the other phase grounded). The ground connections in a real-world system would generally be vertical ground wires running up an electric-utility pole, although some lossy grounding does occur through transformer connections. In this model, ARRL ran a vertical conductor from the unfed phase to an earth ground point and inserted a 50-ohm resistor in the ground lead, to simulate lossy ground and to make the effect of grounding unbalance conservatively minimal.

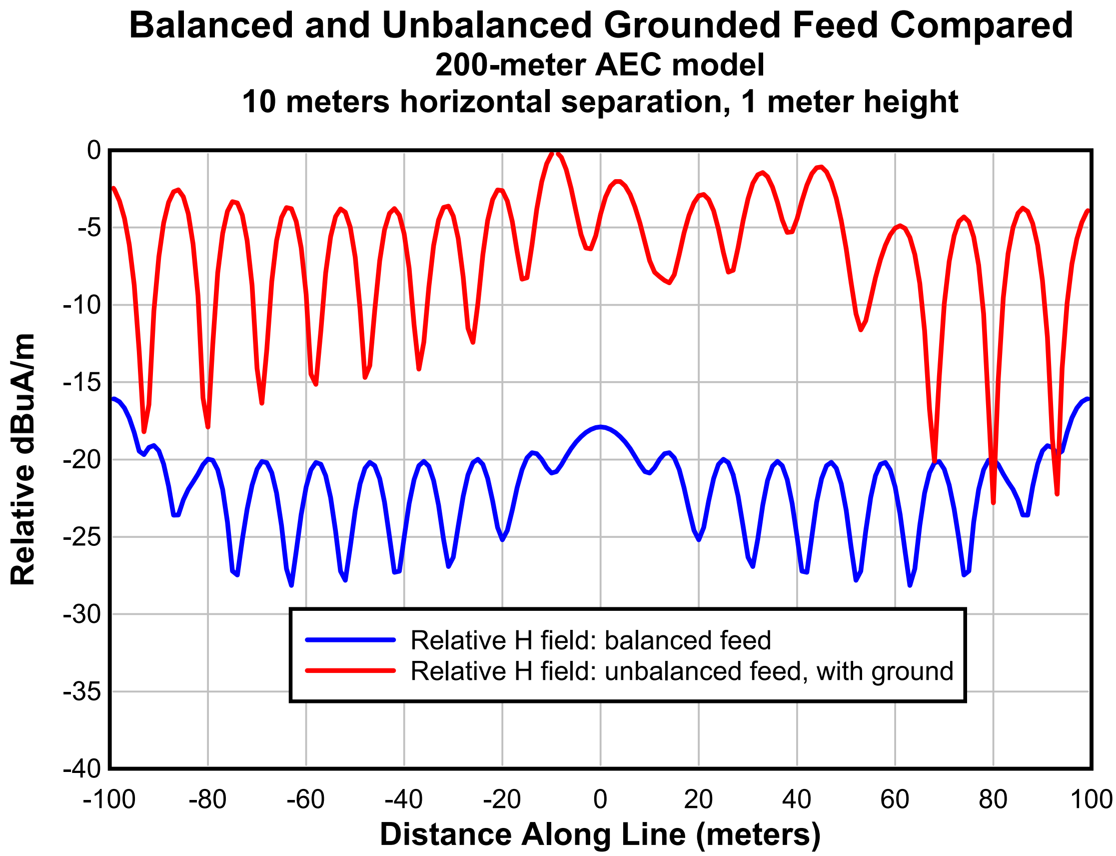

Figure A.4. This shows the significant differences between the predicted field strength from the ideal balanced feed used in the AEC model (lower line) and the fields seen when this model is fed the way that most present BPL systems are fed, with added grounding. The AEC model cannot be used to show the effect of grounding in an EMC environment. This model is intended to show only the conceptual differences between a realistic and idealized model. Note that the ground wire has changed the distribution of field strength such that the point of maximum emissions is well away from the feed source.

6. Fields Strength Along the Power Line

6.1 The modeling results provided by AEC (Table 1 in its filing), the modeled results provided by ARRL and NTIA and the measured results by ARRL, NTIA and others all show that the radiated signal is strong for a considerable distance along a power line. In a number of instances, the maximum field strength is not strongest at the source, but at point significantly distant from the source. This is best seen in the 40-MHz graph in AEC's Table 1 and in a statement from the NTIA Phase I Study report:

"These measurements indicate that there is a strong BPL electric field (relative to noise) along and near the BPL line and in general, the field does not measurably decay with distance from the device (along the power lines). In at least one case, the electric field actually increased with distance from the BPL device."

7. Extrapolation vs Height

7.1 The ARRL, AEC NPRM filings and the NTIA Phase I report provide the FCC with information that shows how measurements made at 1-to-2 meter in height can be extrapolated to other heights. Although AEC's models showed up to 4-dB difference between 1-meter height and other heights, AEC concluded that no extrapolation for height is necessary. ARRL disagrees, noting that all provided data indicating that an extrapolation for height is necessary to protect radio services[3].

7.2 NTIA modeled the electric field, which generally increases somewhat more with height than the magnetic field. NTIA also performed many of its calculations at distances greater than 10 meters. Based on ARRL, AEC and NTIA data indicating that field strength does vary with height, FCC should require a test method that appropriately accounts for the measured and calculated results at different heights. If it does, testing can be done at a relatively low height, providing a safe test method that has established correlation with real-world conditions. NTIA recommends that 5 dB be added to measurements made at 1-meter height. Although real installations do vary from this extrapolation figure, ARRL can support it as a reasonable way to estimate the fields at greater height.

8. Extrapolation vs Distance

8.1 The FCC has proposed a number of BPL-testing procedures. Although ARRL notes that testing in such a complex EMC environment as a BPL installation in a neighborhood grid of overhead power lines can produce reliable results only if many measurements are made at points all up and down the power line, it also recognizes that acceptable testing compromises are necessary to have a test procedure that can be easily duplicated. ARRL supports the FCC and NTIA recommendation to make measurements at 1 meter in height, to permit easy testing of the signal levels up and down the line at close-enough intervals to find the point of maximum emission. ARRL's modeling agrees with the NTIA conclusion that in many cases, the point of maximum emission will be located somewhat distant from the point where the BPL signal is connected to the power line.

8.2 However, as demonstrated in its filed comments, ARRL does not agree that the present test methods allowed in Sec 15.31(f) provides a reasonable way to extrapolate measurements made at one distance to an estimate of what the field strength will be at another distance. In this proceeding, ARRL has provided the FCC with comments that demonstrates why a long power line will radiate as a line source, not as a point source. As a line source, an overhead power line will result in an electric or magnetic field that varies at a 20 dB/distance decade rate, not the 40 dB/decade rate that is applied in the present rules.

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[3] ARRL is most concerned with amateur antennas, many of which will be located at greater height than the power line. The NTIA report was especially concerned with interference to aeronautical communication, all of which will take place at heights greater than power lines.

8.3 In this proceeding and in the NOI, AEC and others have supported the continued use of a 40 dB/decade extrapolation vs distance. ARRL was somewhat puzzled by the results AEC had presented in its filed comments. Although AEC has calculated an extrapolation that approaches 40 dB/decade, it has done so by selecting a height of 1 meter above ground for its calculations. The resultant near-field ground losses significantly increase the rate at which field strength decays with distance, but only for points near ground.

8.4 It its discussion of the NPRM, the FCC correctly notes that the radiated emissions of power lines are typically going to be stronger at points at or equal to the height of the power line. This was confirmed by measurements and calculations done by NTIA and by calculations provided by ARRL. ARRL supports the FCC's stated goal of making measurements intended to find the actual maximum emissions from a radiating conductor. The FCC's proposal to develop an extrapolation vs measurement height is an important part of the principle that testing should be performed to accurately predict the actual maximum radiated field strength. This also means, however, that any slant-range distance extrapolation, if such extrapolation is actually necessary, should be performed in a way that also determines the maximum radiated emissions of the system.

8.5 Although at some frequencies, the fields *along the ground* may decay with distance at a rate somewhat greater than 20 dB/decade, this is not representative of the way that the fields decay at greater heights. Figure A.5 uses the ARRL power-line model with a single phase fed with a single BPL coupler to show the calculated magnetic field on 14 MHz along the power line at a height of 1 meter, at horizontal distances of 10 and 30 meters from the source. The slant-range distances are 13.45 and 31.32 meters respectively. Compare this to Figure A.6, which shows that at a height of 10 meters, the field decays at approximately 20 dB/decade. [1] Note that although the points of maximum field are related by approximately 20 dB/decade, at some points, the field strength at 30 meters is greater than the field strength at 10 meters distance. This clearly shows the importance of having a measurement technique that finds the point of maximum emissions. It also shows that extrapolation is not as simple as a simple formula would imply. Extrapolation must be used carefully, only over relatively small distance ratios and only when necessary.

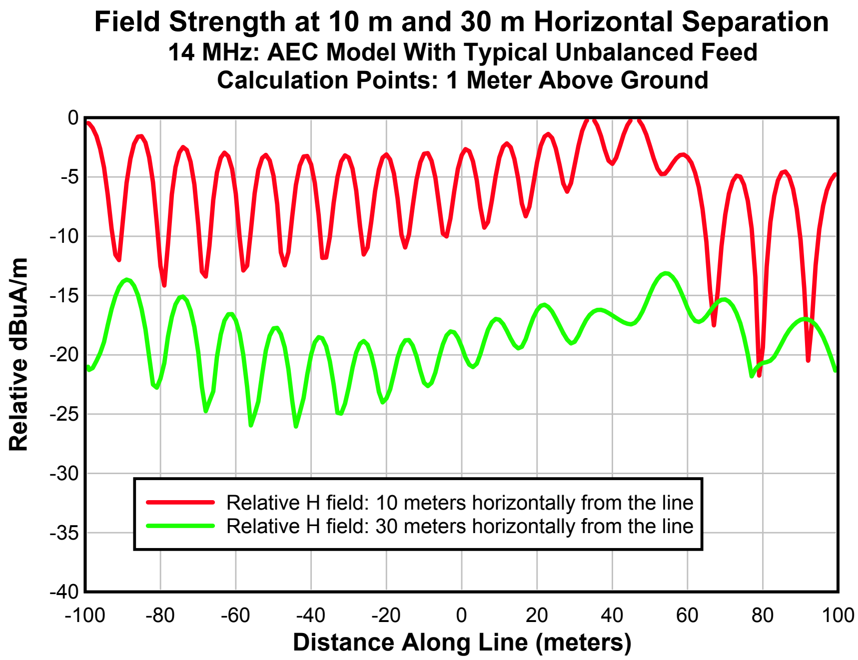

Figure A.5. This shows the way the magnetic fields typically vary along a radiating power line at a frequency of 14 MHz. The calculation points are 1 meter above ground, at horizontal distances of 10 and 30 meters. The extrapolation vs slant-range distance for the maximum field strength is somewhat greater than 20 dB/decade on this band at 1 meter height, but significantly less than 40 dB/decade. Note that the point of maximum field strength at 10 meters distance and the maximum point at 30 meters distance are occurring at different points horizontally down the line. The extrapolation between the two maxima is just over 20 dB/decade.

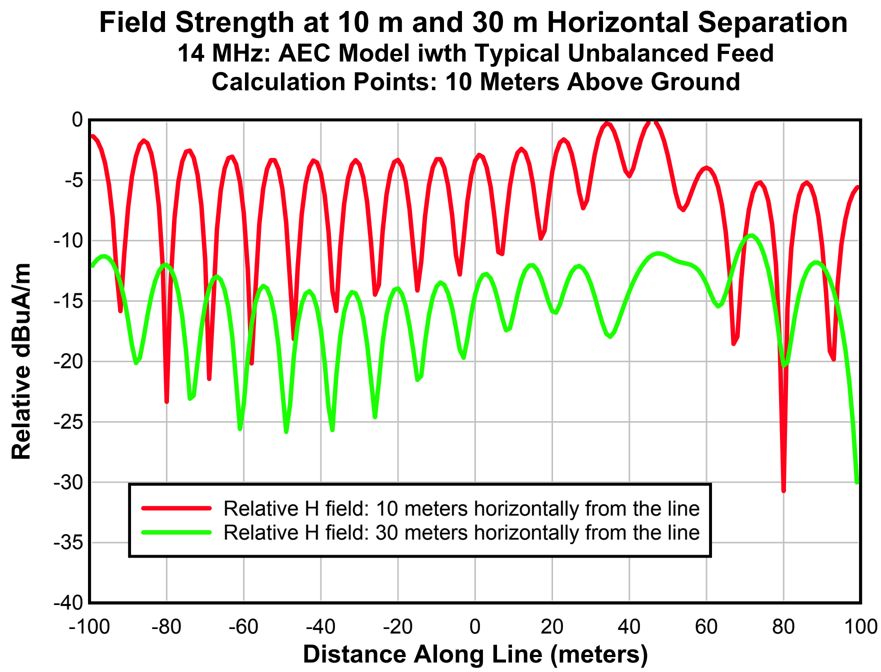

Figure A.6 This shows the way the magnetic fields typically vary along a radiating power line at a frequency of 14 MHz. The calculation points are 10 meters above ground, at horizontal distances of 10 and 30 meters. At the points of maximum emissions at 10 meters height, the extrapolation vs slant-range distance is approximately 20 dB/decade.

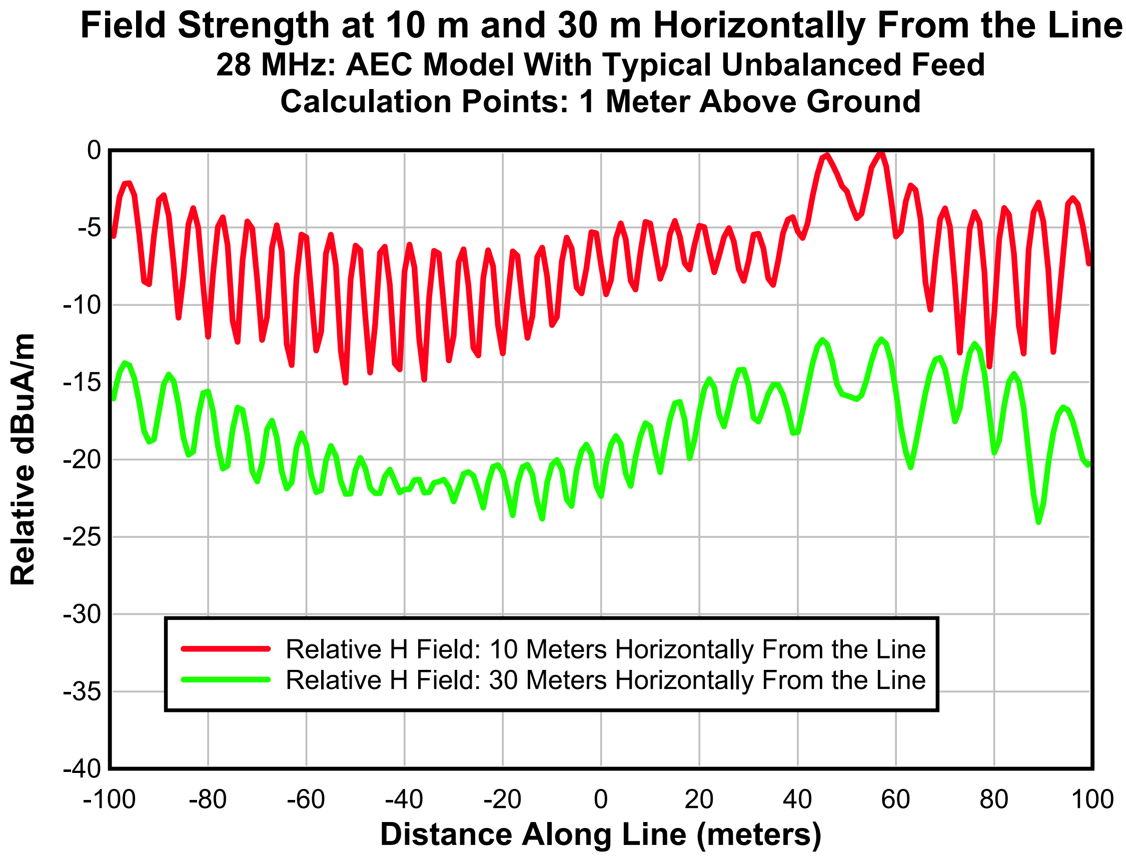

Figure A.7. This shows the way the magnetic fields typically vary along a radiating power line at a frequency of 28 MHz. The calculation points are 1 meter above ground at horizontal distances of 10 and 30 meters. On this frequency, the extrapolation vs slant-range distance is close to 20 dB/decade, even at 1 meter in height.

9. Extrapolation in General

9.1 The above discussion and figures show that extrapolation from a measurement made at one point is generally not going to provide a very accurate result. These are all simple models, and real-world installations are even more complex. In their filing in the NOI, AEC provided the Commission with a line drawing of a multi-legged power line. Figure A.8 reproduces that drawing from the AEC NOI filing. ARRL modeled this power-line drawing, making some assumptions about its dimensions, feeding one phase the same way real-world access BPL systems are fed. A near-field calculation made near this power-line model shows a complex pattern that results from the interaction of the radiation from this line and each of its legs. This is shown in Figure A.8.

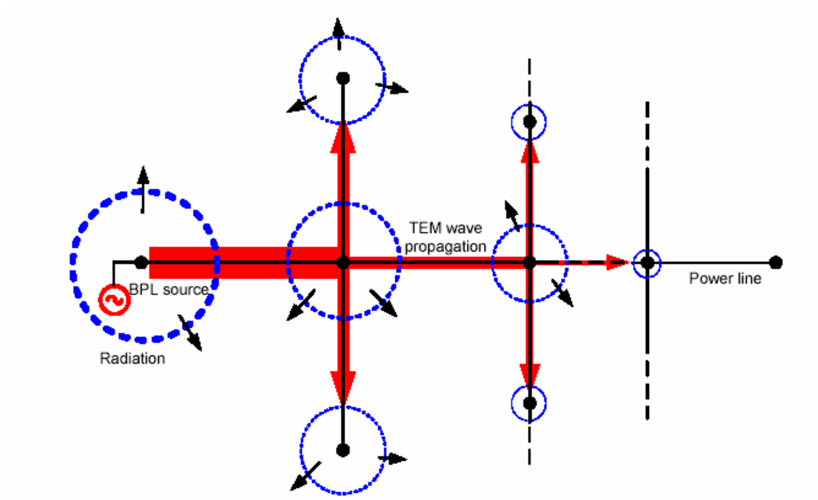

Fig. 3. Conceptual representation of the radiation from a single source BPL. Red line indicates the TEM wave path. Circles indicate the location and strength of radiation points.

Figure A.8. This line drawing was used by AEC to state that power lines radiate only as point sources.

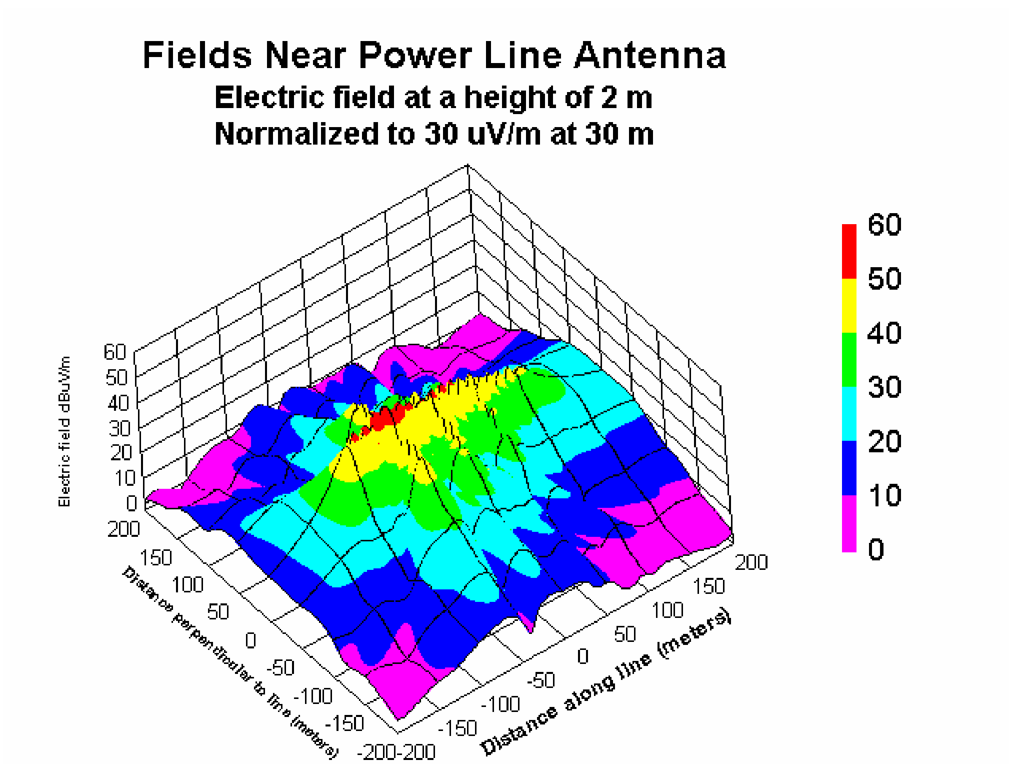

Figure A.9 This is the calculated near-field pattern from a model based on the line drawing AEC provided to the Commission in its filing in the BPL NOI. In this model, the near electric field was calculated at a height of 10 meters from the line. Points closer than 3 meters distance from any part of the line were excluded from this model. This model is not quite as complex as real-world installations, whose radiated fields would generally be even more convoluted. It is simply not possible to determine any typical “actual” extrapolation with distance from this pattern. In the testing proposed by the FCC, far fewer points than this would be available from which to draw any extrapolation data.

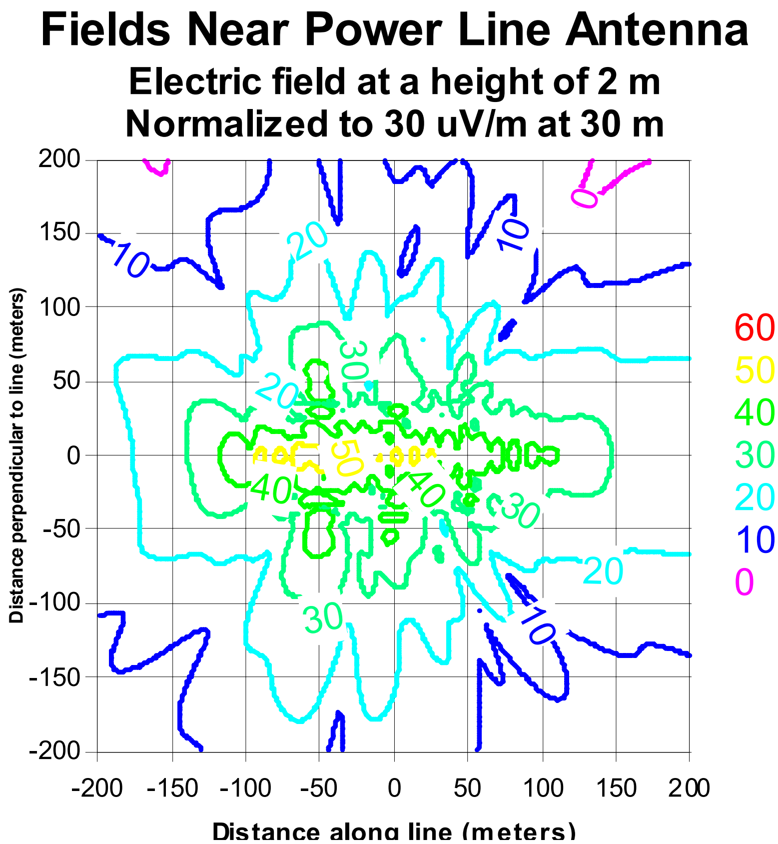

Figure A.10. This shows the same data, plotted in a 2-dimension contour graph. This illustrates that extrapolation from complex radiators must be done only when necessary and over relatively short distances. These data show that the field strength 100 or more meters distance from the power line is strong enough to cause interference to fixed or mobile stations operating near that line. These data correlate well to what was found by NTIA in its studies in BPL areas.

9.2 Although the above example model is less complex than real-world installations, this calculation demonstrates that trying to make extrapolations vs distance for large, complex radiators is far from precise. It is not possible to make a measurement close to this radiator and expect that a simple extrapolation will accurately predict what the point of maximum field strength will be at a distance of 30 meters.

9.3 For small radiators, a somewhat accepted testing practice makes a measurement at two points and then determines the actual extrapolation ratio for that particular emitter. All of the graphs provided in this proceeding show that the field strength oscillates around its average decay vs distance (typically approximately 1/R). This demonstrates that making a few measurements at various points along this varying curve cannot be translated into a simple extrapolation ratio. Figures A.9 and A.10 show the futility of trying to determine a "real" extrapolation from a physically large, complex radiator.

10. 10 Meters Horizontal Separation

10.1 The above discussion and graphical data show that measurements of large radiators on frequencies below 30 MHz must be made carefully, under conditions that are as consistent as possible from one installation to the next. Again, the ideal way to make measurements is to measure many points at the height of the power line. But if done carefully, as described in ARRL's comments in this proceeding, measurements can be made at a lower height and extrapolated to the field strength at greater heights. But in doing so, it is important that other factors do not also get applied to this extrapolation. For example, according to the calculations provided to the FCC by AEC, at horizontal distances significantly closer than 10 meters from the power line, the field strength does not vary much with horizontal distance. If measurements were made in this area and extrapolated to height, it is probable that the actual field strength would be underestimated.

10.2 ARRL and AEC calculations show that at a height of 1 meter, ground attenuation increases the rate at which field strength varies with horizontal distance from the power line. For this reason, if measurements are made at a distance of 30 meters horizontally from the power line, it would be necessary to apply a greater extrapolation for height than the 5 dB recommended by NTIA, which applies reasonably well to measurements made at a distance of 10 meters horizontally from the line. (NTIA calculations suggest that as much as 15 dB of extrapolation for height may be necessary for measurements.)

11. Specify the Limits at 10 meters Distance

11.1 As all of the many factors necessary to define an adequate and useful test method are applied to access BPL systems using overhead electrical wiring, it is apparent that making measurements at a horizontal distance of 10 meters from the power lines offer a number of advantages. These include:

- This is a practical measurement that can be made in virtually all cases
- It allows measurements to be made at a height of 1 meter and a reasonably consistent extrapolation of 5 dB to be used to estimate the maximum field strength that occurs at greater heights
- It avoids underestimating field strength by making measurements too close to a large radiator where AEC and ARRL calculations show that the field strength is significantly less than a simple inverse distance law would predict
- It avoids underestimating field strength by making measurements near ground at significant distances from the antenna
- If minor variations in measurement distance must be made, it minimizes any errors caused by the oversimplification that any extrapolation creates

11.2 For these reasons, ARRL recommends that the FCC's measurement guidelines stress that measurements should be made as close as possible to 10 meters horizontal separation from the power lines.

11.3 However, with all of the advantages of making measurements at 10 meters horizontal separation, the demonstrated errors caused by making measurements at ground level at closer or greater distances and the demonstrated inaccuracies seen in trying to extrapolate measurements made over any but small distance ratios, it appears that changing the Part 15 limits for BPL to a level specified at 10 meters distance would simplify the testing process and its reliability significantly.